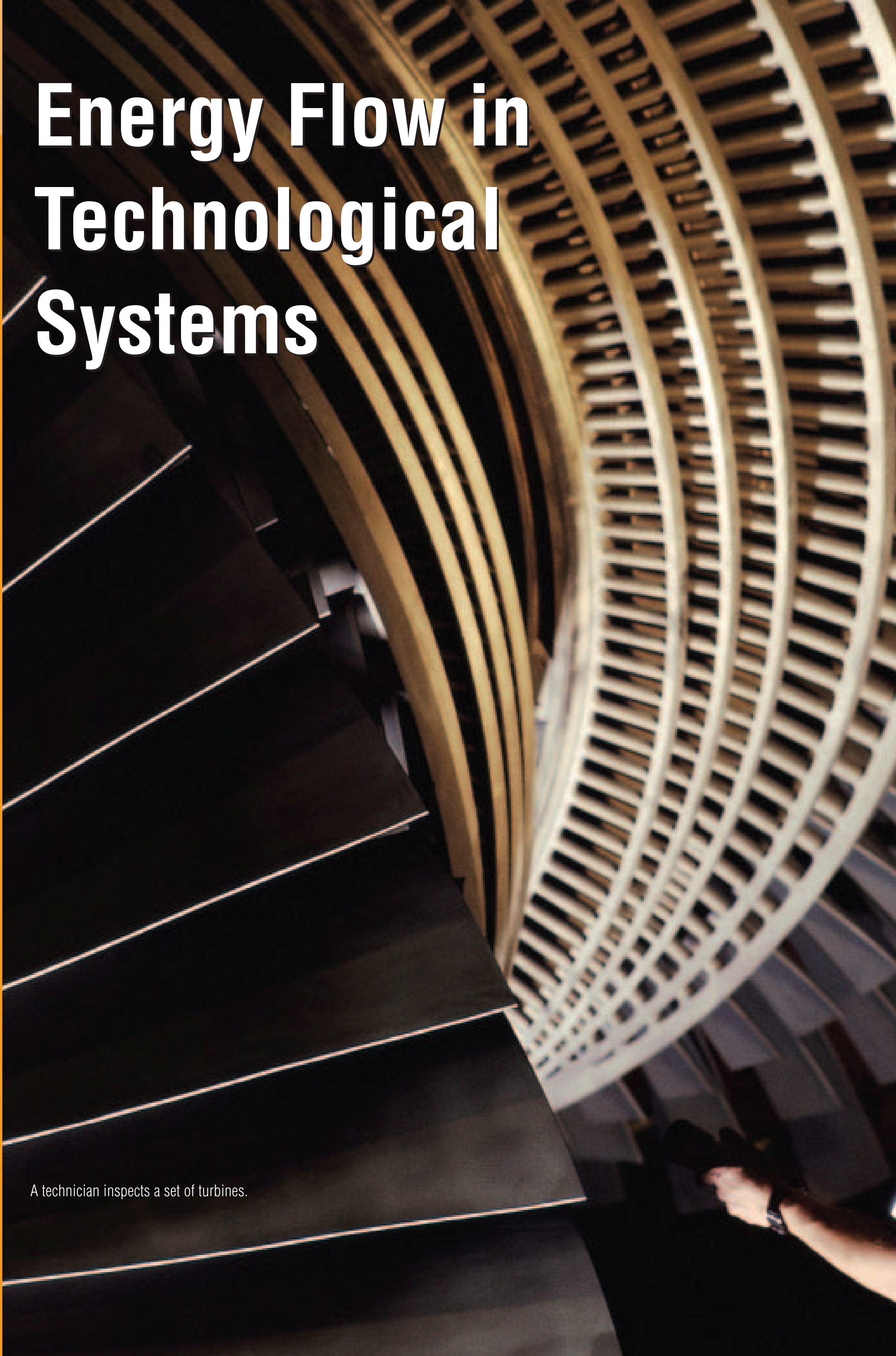
UNIT

B

Energy Flow in Technological Systems



A technician inspects a set of turbines.

In this unit, you will cover the following ideas:

B 1.0 Investigating the energy flow in technological systems requires an understanding of motion, work, and energy.

B1.1 Motion

B1.2 Velocity

B1.3 Acceleration

B1.4 Work and Energy

B 2.0 Energy in mechanical systems can be described both numerically and graphically.

B2.1 Forms of Energy

B2.2 Potential Energy

B2.3 Kinetic Energy and Motion

B2.4 Mechanical Energy

B2.5 Energy Conversions

B 3.0 Principles of energy conservation and thermodynamics can be used to describe the efficiency of energy transformations.

B3.1 Laws of Thermodynamics

B3.2 The Development of Engine Technology

B3.3 Useful Energy and Efficiency

B3.4 Energy Applications

Focus on Science and Technology

While studying this unit, you will be asked to organize your thoughts about how the science of energy and thermodynamics evolved and its corresponding effects on technology. As you work through this unit, think about the following questions:

1. Which came first: science or technology, and is it possible for technological development to take place without help from pure science?
2. How did efforts to improve the efficiency of heat engines result in the formulation of the first and second laws of thermodynamics?
3. How can the analysis of moving objects help in the understanding of changes in kinetic energy, force, and work?
4. Why are efficiency and sustainability important considerations in designing energy conversion technologies?

At the end of the unit, you may be asked to do these tasks:

Case Study Cost-Benefit Analysis of Energy Sources for Transportation

In this case study, you will analyze the costs and benefits of different energy sources for transportation. Based on your analysis, you will recommend which energy sources should be developed.

Project Build an Energy Conversion Device

For the project, you will design and build a Rube Goldberg device to demonstrate energy conversions. You will determine where energy is wasted in the design and suggest ways to reduce energy wastage.

Exploring

Hero's steam engine—the first mechanical device to use heat as a source of energy.

The Apollo spacecraft, which is located at the very top of the rocket, used fuel cells to produce electricity.

The two technological devices shown here were created almost two thousand years apart, but they have several things in common. For their times, they both were unique technological innovations and they both harnessed energy in new ways.

In the 1st century A.D., a Greek engineer named Hero of Alexandria designed the first heat engine. This engine, called a reaction turbine, was a primitive form of the modern steam engine. Hero's steam engine is a metal sphere connected by pipes to a container of water. Two narrow tubes bent at right angles extend from opposite sides of the sphere. The device is filled with water and placed over a fire. As the container is heated, the water boils, and steam is ejected from the nozzles. The sphere then rotates. His invention was the first mechanical device to use heat as a source of energy. However, this invention had no useful purpose; it was just a toy!

For the next 1500 years, people failed to realize the importance of this "hidden" source of energy. The secret of heat as a useful source of energy for machines was rediscovered only in the early 1600s. The start of the Industrial Revolution in the late 1700s brought the need for more sophisticated machines. Hero's steam engine was rediscovered and led to the development of more advanced technologies.

The Apollo spacecraft were among the most technologically advanced inventions of the 20th century and employed an innovative source of energy at the time, a hydrogen fuel cell. In actual fact, the science of the fuel cell was first described in the early 1850s. However, the science of the fuel cell was not applied successfully until the 1970s when it was first used in the Apollo space missions. The fuel cell is still used by NASA today to generate electricity in the space shuttle.

Fuel cell technology is no longer just being used for space flights. At the forefront of fuel cell research is a Canadian company called Ballard Power Systems, based in Vancouver. Although this company already has fuel-cell-powered buses operating in Canada and the U.S., it has unveiled four prototype fuel cell vehicles for DaimlerChrysler.

Activity B1

QuickLab

All Kinds of Energy

You probably use the word "energy" often in daily conversation. Did you ever stop to wonder how many different types of energy there are and where they are found?

Purpose

To identify different types of energy

Procedure

1. Go to each station, perform the procedures listed below, and record your observations. List the types of energy that come to mind at each station.

Station 1: Shine the light source on the radiometer.

Station 2: Turn on the flashlight.

Station 3: Bring a magnet close to a small piece of iron.

Station 4: Pull the pendulum ball back and release it.

Station 5: Use a spatula to place a small amount (approximately 5 g) of baking soda on an evaporating dish, and using the medicine dropper, place 1 or 2 drops of vinegar on the baking soda. Observe and then clean the evaporating dish.

Station 6: Place the hanging mass, which is attached to the block of wood, over a pulley at the edge of the ramp and allow the mass to fall to the table.

Station 7: Rub the ebonite rod with the fur and then bring the rod close to the bits of paper.

Station 8: Wind up the car and let it go.

Questions

1. How many different types of energy came to mind when you visited the stations?
2. Which stations demonstrated a type of energy that you did not know how to describe?
3. Which type of energy did you observe most commonly?
4. Did these demonstrations make you aware of some types of energy that you had never heard of?

Extending

5. Did you observe any transformations from one type of energy to another? Explain your answer.

Materials and Equipment

Station 1: a radiometer and a light source

Station 2: a battery-operated flashlight

Station 3: a magnet and small pieces of iron

Station 4: a pendulum attached by a string to a retort stand

Station 5: a beaker with vinegar, a dish of baking soda, and a medicine dropper

Station 6: a ramp, a pulley, a string, a mass, and a block of wood

Station 7: an ebonite rod, a piece of fur, and tiny bits of paper

Station 8: a wind-up car

UNIT B

1.0

Key Concepts

In this section, you will learn about the following key concepts:

- one-dimensional motion
- work

Learning Outcomes

When you have completed this section, you will be able to:

- define, compare, and contrast scalar and vector quantities
- describe displacement and velocity quantitatively
- define acceleration quantitatively as a change in velocity during a time interval: $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$
- explain that, in the absence of resistive forces, motion at constant speed requires no energy input
- recall from previous studies the operational definition for force as a push or a pull, and work as energy expended when the speed of an object is increased or when an object is moved against the influence of an opposing force
- investigate and analyze one-dimensional scalar motion and work done on an object or system using algebraic and graphical techniques

Investigating the energy flow in technological systems requires an understanding of motion, work, and energy.

FIGURE B1.1 Competitors in the famous *Tour de France*

The *Tour de France* is considered to be the world's most prestigious bicycle race. Held in July, it winds its way through most of France. The course is divided into 20 stages. The overall winner each day gets to wear a prized yellow jersey. Perhaps the most gruelling stage of the tour occurs when the competitors reach the Pyrenees, where steep mountain roads test the endurance of the riders (Figure B1.1).

Pedalling a bike up a long steep hill can be extremely challenging and exhausting. When every muscle in your legs begins to feel like jelly, you might wish that someone could push you the rest of the way up the hill.

Humans always want to make life easier, and throughout history, we have invented technological devices and systems to help us perform heavy tasks. In designing new technological devices, people have discovered that many forms of energy can be harnessed to do work. Bicycles first used leg power, then motorbikes used energy from gasoline. Now, engineers have developed a prototype of a bicycle that uses energy from a hydrogen fuel cell. (Of course, this new fuel cell bike would never be used in the *Tour de France*, where "legwork" rules!)

The development of advances in technological systems depends on knowledge of the science involved and the link to technology. In this section, you will learn how studies of motion are related to the scientific concept of energy. By analyzing different types of motion, you will gain an understanding of the important relationships between forces and motion. After establishing these relationships, you will learn how they lead to a scientific concept of work. Finally, you will learn that only through a thorough understanding of work can the secret of the concept of energy be revealed.

B1.1 Motion

Motion is all around us. It may be as simple as an object moving in a straight line at a constant speed, like the MAGLEV train in Figure B1.2, or as complicated as the circular motion of a Ferris wheel.

Motion is everywhere and easy to recognize, but it was not always easy to describe. The early Greek philosophers realized that motion involved an object travelling a certain distance in a time interval. However, they could not describe motion because they did not understand the idea of rate or how something changes in a certain amount of time.

Uniform Motion

We can analyze the motion of an object only if we compare the object's position to another point. This point is called a reference point, and all observations are made in relation to that point. For example, suppose you are floating on an air mattress on a swimming pool. You may not realize you are moving until you notice how far you are from the stairs where you entered the pool. The set of stairs is your reference point.

The **motion** of an object occurs when an imaginary line joining the object to the reference point changes in length or direction or both (Figure B1.3). In some cases, we may be interested only in the change in length of the line as an indication that motion has occurred. In other cases, we may be interested in both the change in length and the change in direction. Once we know that motion is present, we can then describe the type and the rate of motion.

In this section, we will concentrate on the simplest type of motion: uniform motion. **Uniform motion** is a term used to describe an object that is travelling at a constant rate of motion in a straight line. Many situations occur where an object appears to have uniform motion, but this type of motion is nearly impossible to maintain for long periods. For example, a car travels along a straight highway with the cruise control set at 100 km/h. The car appears to maintain a constant rate of motion, but various forces act to slow the car down, such as the friction of the tires on the road and wind resistance. Even with cruise control on, the car's rate of motion fluctuates around 100 km/h as its engine attempts to maintain the set rate. It is also almost impossible to maintain motion in a perfectly straight line in everyday situations.

info **BIT**

In Japan, MAGLEV (short for magnetic levitation) trains achieve uniform motion by reducing friction. They do this by eliminating wheels and tracks. Instead, the train hangs down on either side of a guideway. Both the train and the guideway contain very high-powered magnets. The two sets of magnets repel each other, causing the train to rise (levitate) above the guideway and move forward. These trains can reach speeds of about 400 km/h, much faster than the speed of the fastest conventional trains.

FIGURE B1.2 This MAGLEV train displays uniform motion. It travels at a constant rate in a straight line, and it experiences almost no friction.

FIGURE B1.3 You can tell that the person has moved because the length of the imaginary line joining her to the bus stop changes between (a) and (b).

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Earth is travelling through space around the Sun at an average speed of about 107 000 km/h.

Average Speed

The car in the example above has a rate of motion or speed of 100 km/h. Because uniform motion is difficult to maintain, the term **average speed** is usually used. Average speed is uniform motion that involves travelling a distance in a specified time.

You might be able to estimate the average speed of an object based on your day-to-day experiences of motion. But to describe the speed of an object more accurately, you have to analyze it quantitatively with mathematical formulas or graphs.

Using Formulas to Analyze Average Speed

Use the following equation to determine the average speed of an object.

$$\text{average speed} = \frac{\text{distance travelled}}{\text{time elapsed}}$$

$$v = \frac{\Delta d}{\Delta t}$$

$$= \frac{d_{\text{final}} - d_{\text{initial}}}{t_{\text{final}} - t_{\text{initial}}}$$

Example Problem B1.1

A person walks 10.0 m away from a stop sign in 5.00 s. What is the average speed of the person?

Average speed:

$$v = \frac{\Delta d}{\Delta t}$$

$$= \frac{10.0\ \text{m} - 0.0\ \text{m}}{5.00\ \text{s} - 0.00\ \text{s}}$$

$$= \frac{10.0\ \text{m}}{5.00\ \text{s}}$$

$$= 2.00\,\frac{\text{m}}{\text{s}}$$

The person walked at a speed of 2.00 m/s.

Practice Problems

1. A huge ocean wave, or tsunami, travels a distance of 4.0×10^6 m in 3.6×10^4 s. Calculate the average speed of the tsunami.
2. A Concorde airplane could fly at an average speed of 694 m/s. Calculate how long it would have taken the Concorde to fly around the world, which is approximately 4.00×10^7 m.
3. An electric train is travelling at an average speed of 6.9 m/s for 4.0 s. Calculate the distance travelled by the train.

Using Graphs to Analyze Average Speed

Creating a picture in your mind of an average speed can be difficult using formulas alone. A graph is an important tool for studying uniform motion because it not only shows the relationship between the two variables, but also provides a visual representation of the motion. For uniform motion, there are two types of graphs that can be used. They are a distance–time graph and a speed–time graph.

Plotting a Distance–Time Graph

Suppose a motorboat is travelling at a uniform speed. The boat passes marker buoys placed 5 m apart, which act as a measuring scale. As the boat passes the first marker, a person on shore starts to record the distance the boat travels away from the first marker every 2.0 s. Table B1.1 shows the measurements taken by the person on shore.

The graph in Figure B1.4 describes the motion of the motorboat. The line of best fit on the graph is a straight line with a positive slope. This indicates a direct linear relationship between the distance travelled and the time taken to travel the distance. This means that as time increases, the distance travelled also increases. Since the graph is a straight line, the change in distance travelled in relation to the time intervals is constant. This shows that the motorboat has uniform motion. As long as the line is a straight line, the object represented in the graph is displaying uniform motion. If the line of best fit were a curve of any type, this would mean the object was changing distance travelled in equal time intervals. In other words the object would be either speeding up or slowing down.

The slope of the line in Figure B1.4 also tells you something about the motion. The slope of the graph may be determined using the following formula:

TABLE B1.1 Progress of Boat Travelling past Marker Buoys

Time t (s)	Distance from First Marker d (m)
0.0	0
2.0	10
4.0	20
6.0	30
8.0	40
10.0	50

$$\begin{aligned}
\text{slope} &= \frac{\text{rise}}{\text{run}} \\
&= \frac{\text{change in distance}}{\text{change in time}} = \frac{\Delta d}{\Delta t} \\
&= \text{speed} \qquad\qquad \text{Since } v = \frac{\Delta d}{\Delta t} \\
&= \frac{\Delta d}{\Delta t} \\
&= \frac{d_f - d_i}{t_f - t_i} \\
&= \frac{30\text{ m} - 10\text{ m}}{6.0\text{ s} - 2.0\text{ s}} \\
&= \frac{20\text{ m}}{4.0\text{ s}} \\
&= 5.0\ \frac{\text{m}}{\text{s}}
\end{aligned}$$

Therefore the average speed, v, is 5.0 m/s.

The slope of a distance–time graph is a visual representation of the speed of an object. A greater or steeper slope indicates a faster speed and a lesser slope indicates a slower speed.

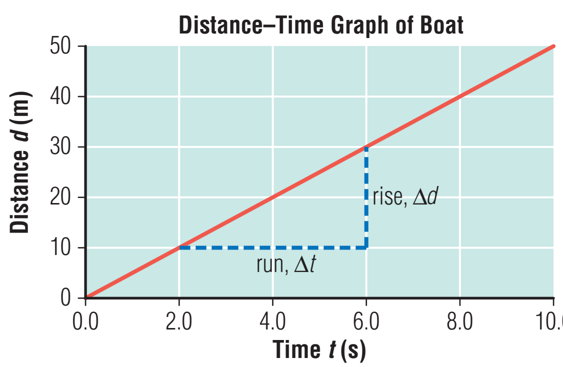


FIGURE B1.4 A distance–time graph produced from the data in Table B1.1

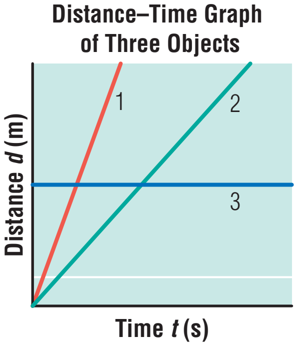


FIGURE B1.5 A distance–time graph showing three different motions

Figure B1.5 is a distance–time graph showing the motion of three objects. Line 1 shows an object with uniform motion. Line 2 shows an object with slower uniform motion than line 1. Line 3 shows a uniform motion of 0 m/s, meaning the object is at rest (not moving).

Example Problem B1.2

The data in Table B1.2 were collected for an object travelling at a uniform speed.

a) Draw a distance–time graph for the data in the table.
b) Determine the slope of the line.
c) What value does the slope of the graph represent?

TABLE B1.2 Time and Distance Data for Example Problem B1.2

Time t (s)	Distance from First Marker d (m)
0.0	0.0
1.0	3.9
2.0	8.0
3.0	12.2
4.0	15.9
5.0	20.1

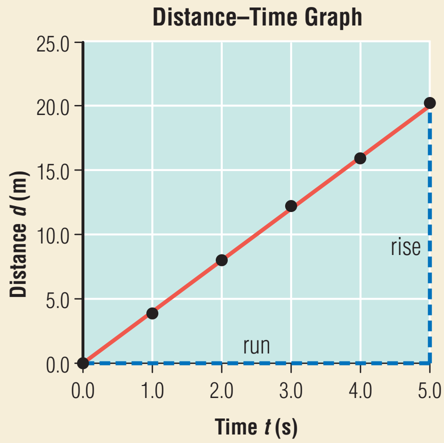


FIGURE B1.6 A distance–time graph for the data from Table B1.2

a) Figure B1.6 shows the graph drawn from the data in Table B1.2.

b) $$\text{slope} = \frac{\text{rise}}{\text{run}}$$
$$= \frac{20.0\ \text{m} - 0.0\ \text{m}}{5.0\ \text{s} - 0.0\ \text{s}}$$
$$= \frac{20.0\ \text{m}}{5.0\ \text{s}}$$
$$= 4.0\ \frac{\text{m}}{\text{s}}$$

c) Since slope = speed, the average speed of the object was 4.0 m/s.

Practice Problem

4. The data in Table B1.3 were collected for a jet travelling at a uniform speed.

a) Draw a distance–time graph for the data in the table.
b) Determine the slope of the line.
c) What value does the slope of the graph represent?

TABLE B1.3 Time and Distance Data for a Jet Travelling at Uniform Speed

Time t (s)	Distance from First Marker d (m)
0.0	0
1.0	490
2.0	1020
3.0	1490
4.0	2010
5.0	2480

Plotting a Speed–Time Graph

Suppose the motorboat mentioned previously is travelling past the same marker buoys. This time, a person on shore uses a radar gun to record the speed of the motorboat every 2.0 s. The data are shown in Table B1.4.

The graph of the data (Figure B1.7) also describes the motion of the motorboat. The line of best fit is a straight line, indicating a linear relationship between the speed of the boat and the time elapsed. The line is horizontal, which means that as the time elapsed increases, the speed remains constant. This should be the case, since the boat has uniform motion.

You can confirm that the speed is uniform by calculating the slope of the graph. The slope of the line can be determined as follows:

$$\begin{aligned}
\text{slope} &= \frac{\text{rise}}{\text{run}} = \frac{\Delta v}{\Delta t} \\
&= \frac{5.00\,\frac{\text{m}}{\text{s}} - 5.00\,\frac{\text{m}}{\text{s}}}{10.0\text{ s} - 0.0\text{ s}} \\
&= \frac{0.00\,\frac{\text{m}}{\text{s}}}{10.0\text{ s}} \\
&= 0.0\,\frac{\text{m}}{\text{s}^2}
\end{aligned}$$

A slope of 0.0 m/s^2 confirms that the motion is uniform.

You can determine the distance the boat travelled by calculating the area under the line of the graph. The area under the line of best fit of the speed–time graph in Figure B1.7 is determined as follows:

$$\begin{aligned}
\text{area under the line} &= \text{area of a rectangle} \\
&= \text{length} \times \text{width} \\
\text{area} &= (v)(\Delta t) \\
&= (5.00\text{ m/s})(10.0\text{ s} - 0.0\text{ s}) \\
&= (5.00\,\frac{\text{m}}{\cancel{\text{s}}})(10.0\,\cancel{\text{s}}) \\
&= 50\text{ m}
\end{aligned}$$

Since the speed formula, $v = \frac{\Delta d}{\Delta t}$, can be rearranged to $(v)(\Delta t) = \Delta d$, the area under the line is the same as Δd. Thus, the area under the line of a speed–time graph indicates the distance travelled in the time period.

If the line of best fit were a straight line with a slope $\frac{\Delta d}{\Delta t}$ other than zero, then the line would represent an object that is changing its speed as time passes. From the slant of the slope of the line of a speed–time graph, you can tell whether the speed of the object is increasing or decreasing (Figure B1.8). You will learn more about changes in speed in section B1.3.

TABLE B1.4 Speed of a Boat Passing Marker Buoys

Time when Boat Passes Marker t (s)	Speed of the Boat as It Passes Each Marker v (m/s)
0.0	5.00
2.0	5.00
4.0	5.00
6.0	5.00
8.0	5.00
10.0	5.00

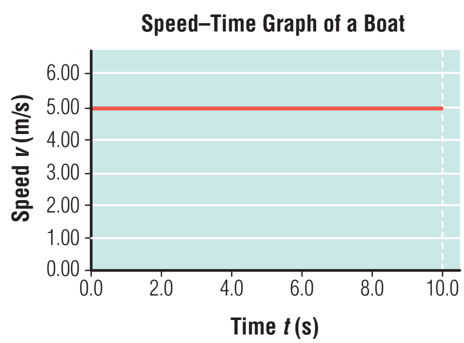


FIGURE B1.7 A graph of the speed of the motorboat as a function of time

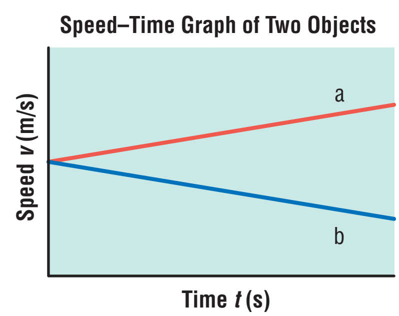


FIGURE B1.8 A line sloping upward (a) indicates that the speed is increasing. A line sloping downward (b) indicates that the speed is decreasing, so the object is slowing down.

Skill Practice Using Significant Digits

Student Reference 6

Throughout this unit, you will be making calculations. It is important that you use the correct number of significant digits in your answers. Review the rules for determining significant digits and for operations involving significant digits in Student Reference 6: Math Skills, then answer the following questions and complete the calculations.

1. Indicate the number of significant digits each of the following measurements has.

a) 3.1415 m

b) 2001.10 g

c) 34 000 g

d) 0.0027 s

e) 8.1 km

2. Solve the following problems. Give your answers to the correct number of significant digits.

a) 3.20 cm + 2.1 cm

b) 4.55 km − 1.6 km

c) 3.20 km × 1.11 km

d) 45.0 km ÷ 2.1 h

3. Solve the following problems. Give your answers to the correct number of significant digits.

a) 0.00221 ÷ (1.006 + 2.23)

b) 347 × 7.48 ÷ 21.2

c) 6.4(9748 + 17.57)

d) $\dfrac{0.56 - 0.05}{8.436 - 0.2}$

*re*SEARCH

Speed is an important physical quantity in describing motion. Use the Internet or your local library to research and answer the following questions. What is the fastest speed recorded for a human in a 100-m race and in a marathon? What are the fastest speeds recorded for an animal, a fish, an automobile, a boat, an airplane, and a spacecraft? Write a brief summary of your findings, describing how these speeds were determined. Begin your search at www.pearsoned.ca/school/science10

Example Problem B1.3

The data in Table B1.5 were collected for an object travelling at a uniform speed.

a) Draw a speed–time graph for the data in the table.

b) Determine the slope of the line. How does the slope indicate that the object is travelling with uniform speed?

c) Determine the area under the line for the time interval, t = 0.0 s to t = 5.0 s. What does this value represent?

TABLE B1.5 Time and Speed Data for Example Problem B1.3

Time t (s)	Speed v (m/s)
0.0	5.8
1.0	6.0
2.0	6.2
3.0	6.0
4.0	5.9
5.0	6.1

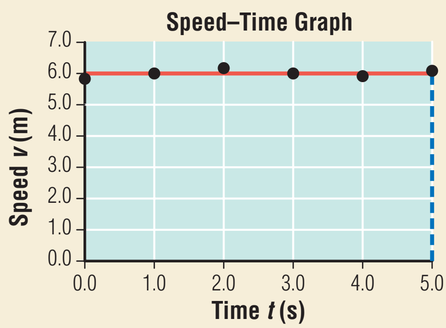


FIGURE B1.9 Time and speed graph for data from Table B1.5.

a) Figure B1.9 shows the graph drawn from the data in Table B1.5.

b) $\text{slope} = \dfrac{\text{rise}}{\text{run}}$

$$= \frac{6.0\ \frac{\text{m}}{\text{s}} - 6.0\ \frac{\text{m}}{\text{s}}}{5.0\ \text{s} - 0.0\ \text{s}}$$

$$= \frac{0.0\ \frac{\text{m}}{\text{s}}}{5.0\ \text{s}}$$

$$= 0\ \frac{\text{m}}{\text{s}^2}$$

A slope = 0 indicates that the speed was uniform.

c) $\text{area} = \text{length} \times \text{width}$

$$= (v)(\Delta t)$$

$$= (6.0\ \frac{\text{m}}{\cancel{\text{s}}})(5.0\ \cancel{\text{s}})$$

$$= 30\ \text{m}$$

The area represents the distance travelled.

Practice Problem

5. The data in Table B1.6 were collected for an object travelling at a uniform speed.
   a) Draw a speed–time graph for the data in the table.
   b) Determine the slope of the line. How does the slope indicate that the object is travelling with uniform speed?
   c) Determine the area under the line for the time interval, $t = 0.0$ s to $t = 5.0$ s. What does this value represent?

TABLE B1.6 Time and Speed Data for Practice Problem 5

Time t (s)	Speed v (m/s)
0.0	9.8
1.0	10.0
2.0	10.2
3.0	10.0
4.0	9.9
5.0	10.1

Skill Practice Taking Measurements

In Activity B2, you will be taking measurements using two different measuring instruments. One of the most important skills in any science course is being able to use measuring instruments properly. For any type of instrument, your measurement must include a final digit that is an estimated digit. For example, when using a ruler that has the smallest grading in millimetres, the final digit of your measurement should be in tenths of a millimetre, as shown in Figure B1.10.

The correct measurement for the length of the line is not 2.3 cm or 2.4 cm but 2.35 cm.

1. Use your ruler to measure the width, length, and thickness of this textbook in centimetres. Record the data in your notebook. To how many decimal places can you measure with your ruler?

2. Use a stopwatch to measure the time taken in seconds for a ball to hit the floor if dropped from your desktop. Repeat this procedure several times. Record the data in your notebook. To how many decimal places were you able to measure the time?

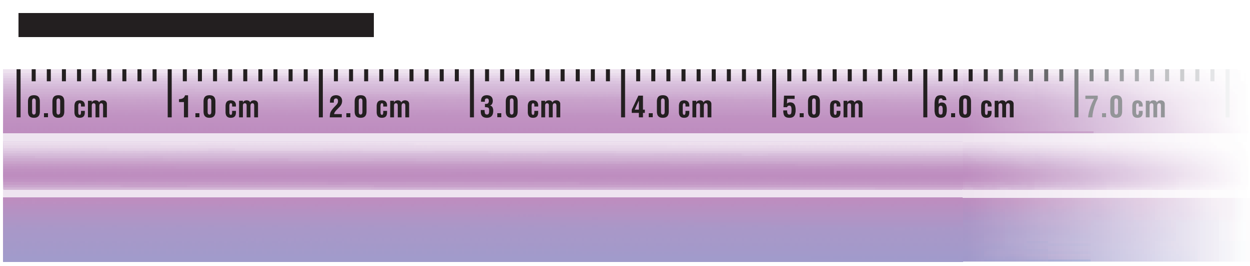


FIGURE B1.10 A ruler with millimetre gradings

Activity B2

Inquiry Lab

Student Reference 5, 7

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Studying Uniform Motion

The Question

What kind of motion do falling dominoes exhibit?

The Hypothesis

State a hypothesis concerning the motion of the falling dominoes. Be sure to write an "if/then" statement.

Variables

Identify the type of data you will collect to support your hypothesis. State the manipulated, responding, and controlled variables in this investigation.

Materials and Equipment

65 dominoes (2.5 cm x 5.0 cm)

metre-stick or measuring tape

5 stopwatches

masking tape

Procedure

1. Paste 3.00 m of masking tape on a flat table or countertop, making sure that the masking tape is perfectly straight.
2. At one end of the masking tape, make a pencil mark designating the starting position, 0.00 cm. From this starting position, make a mark every 50.00 cm on the masking tape, using the metre-stick or measuring tape.
3. Place the metre-stick or measuring tape parallel to the masking tape at the start position so that the 0.00 mark aligns with the 0.00 mark on the masking tape.
4. Place the first domino at the 0.00 cm mark on the masking tape (Figure B1.11). Place the next domino at 4.00 cm, and continue lining up the dominoes every 4.00 cm until you have at least 65 dominoes in a line.
5. One member of the group (each group has 6 students) positions him- or herself at the 0.00 cm, 50.00 cm, 100.00 cm, 150.00 cm, 200.00 cm, and 250.00 cm marks. Each student has a stopwatch except for the student at the 0.00-cm mark.
6. When the student at the 0.00-cm mark says "Start," he or she pushes over the first domino and the other students start their stopwatches.
7. Each student stops his or her stopwatch when the toppling dominoes reach his or her mark on the tape.
8. Record your results in a table like the one below.
9. Do at least three trials of the experiment, and calculate the average values of the times. Record the average values in your notebook.

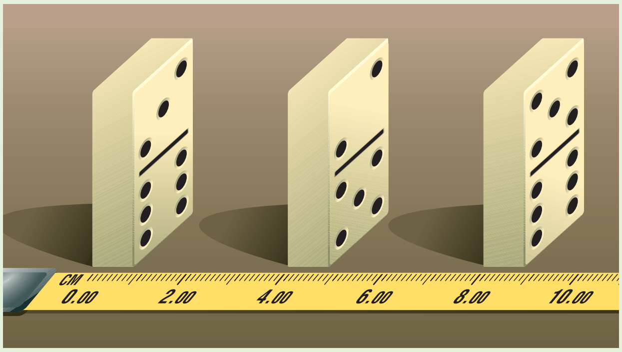


FIGURE B1.11 Step 4

Distance d (cm)	Time Elapsed t (s)
0.00	0.0
50.00	
100.00	

Analyzing and Interpreting

1. Identify the manipulated and the responding variables in this experiment.

2. Draw a distance–time graph. Remember that, although the manipulated variable should be on the x-axis of your graph, time (which is the responding variable in this experiment) is always plotted on the x-axis.
3. What type of line is your line of best fit?
4. What type of motion is depicted by your line of best fit?
5. Determine the slope of the line of best fit of the graph. What does this value represent?
6. From your data, calculate the speed during each time interval by determining the distance travelled during the interval and substituting the values in the formula
$$v = \frac{\Delta d}{\Delta t}$$
7. Using your calculated values for the speed of each time interval, create a table like the one below. Make sure your table has a title.

Time Interval Δt (s)	Speed v (m/s)

8. Draw a speed–time interval graph.
9. On the graph, determine the slope of the line of best fit.
10. Indicate on the graph what the value of this slope represents.
11. On the graph, determine the area under the line for the entire time.
12. Indicate on the graph what the value of this area represents.

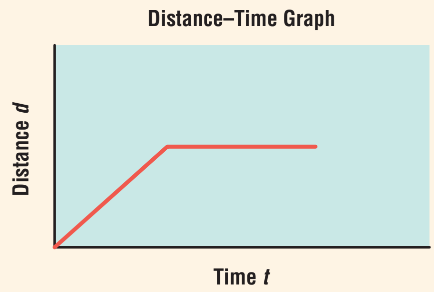
Forming Conclusions

13. Study the distance travelled–time graph. Explain how this graph shows that the falling dominoes are displaying uniform motion.
14. Study the speed–time graph. Explain how this graph shows that the falling dominoes are displaying uniform motion.

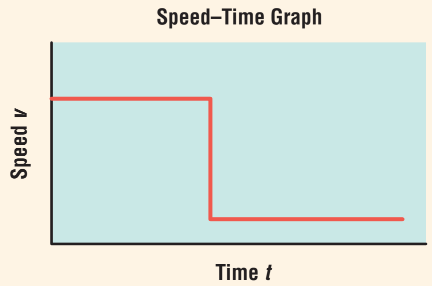
B1.1 Check and Reflect

Knowledge

1. How can you determine if an object is in motion?
2. When is an object travelling in uniform motion?
3. What two quantitative methods can you use to analyze uniform motion?
4. What can you determine from the following calculations?
   a) the slope of a distance–time graph
   b) the slope of a speed–time graph
   c) the area under the line of a speed–time graph
5. Describe the motion of an object as shown in each segment of the graph in the right column. The graph represents the distance travelled as a function of time.



6. Describe the motion of an object as shown in each segment of the graph below. The graph represents the speed as a function of time.



Applications

7. Which of the following situations most closely describes uniform motion? Explain your answer.
  a) a person sliding down a waterslide
  b) water falling down a waterfall
  c) electricity flowing through a wire

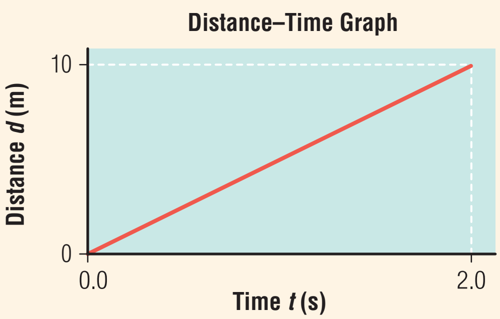
8. A skateboarder travels 50.0 m in 12.0 s. What is the average speed of the skateboarder?

9. A baseball player throws a ball a distance of 45.0 m at a speed of 30.0 m/s. How long is the ball in flight?

10. An airplane flies at a speed of 990 km/h for 4.10 h. How far does the airplane travel?

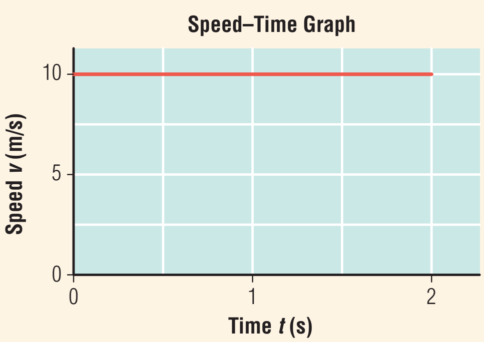
11. A bird is flying 6.00 km/h in a straight line at a constant rate. How long will it take the bird to travel 30.0 km?

12. A graph of an object travelling in uniform motion is shown below.

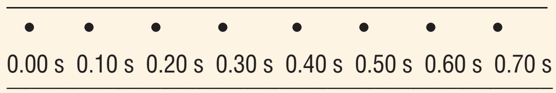


  a) Determine the slope of the graph.
  b) What quantity does the slope of this graph represent?

13. A graph of an object travelling in uniform motion is shown below.
  a) Determine the slope of the graph.
  b) What quantity does the slope represent?



14. The ticker tape shown below shows a record of the motion of an object on a straight horizontal track. The marks were produced by a spark timer set at 10 sparks per second.



  a) In your notebook, create a data table that records the time and the distance travelled by the object from the starting point at 0.0 s.
  b) Draw a distance–time graph of the data in your table.
  c) Calculate the slope of the line of your graph.
  d) What information does the slope of this graph give you?

15. Using the same ticker tape shown in question 14, answer the following questions.
  a) In your notebook, create a data table that records the average speed of the object at the end of each time interval.
  b) Draw a speed–time graph of the data in your table.
  c) Calculate the area under the line at the 0.70 s mark.
  d) What information does the area under the line give you?

16. A person walks 15.0 m in 5.00 s, and then walks 12.0 m in 10.00 s. What is the average speed of the person?

17. A person walks at a speed of 2.00 m/s for 10.00 s, and then walks at a speed of 1.50 m/s for 8.00 s. What is the average speed of the person?

Extensions

18. Sketch a distance–time graph with three lines on it: one that represents a slow-moving object; one for a fast-moving object; and one for an object that is not moving.

19. Why is it so difficult to find examples of objects travelling at uniform motion?

B1.2 Velocity

You have probably heard people use the term "velocity" when they describe how fast a car is going. Most of the time, they are actually referring to "speed." As you learned in section B1.1, speed describes the rate of motion of an object. **Velocity** describes both the rate of motion and the direction of an object. You can determine the average speed of a car by looking at its speedometer. To determine its average velocity, you need both the speedometer and a compass, to show you its direction.

Scalar and Vector Quantities

The difference between speed and velocity is that speed is a **scalar quantity**, and velocity is a **vector quantity**. All quantities in science can be classified as either scalar or vector quantities. A scalar quantity is one that only indicates "how much" (the magnitude) of the quantity. A vector quantity indicates "how much" (the magnitude) *and* the direction of the quantity. A vector quantity is written with a vector arrow above the symbol for the measured quantity. For example, the symbol for speed is v, and the symbol for velocity is $\vec{v}$.

Distance Travelled and Displacement

Distance travelled and displacement are two other examples of related scalar and vector quantities. **Distance travelled** is a scalar quantity. It is a measurement of the change in distance of an object moving from a starting reference point. In Figure B1.12, the person moves from the bus stop to a point 10 m away from it. You would record the distance the person moved as $\Delta d = 10$ m. This indicates that the object (the person) moved 10 m from the reference point (the bus stop). The "Δ" shows that the number is a change in a quantity.

FIGURE B1.12 The person has moved 10 m from the bus stop, so the distance travelled is written as $\Delta d = 10$ m.

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The numbering of airport runways illustrates the importance of including direction when describing motion. Airport runways are numbered according to their angle from magnetic north at 0°. The runway number indicates the runway's angle from magnetic north in a clockwise direction, with the last "0" omitted. If the runway's heading is 40° from magnetic north, the runway is called runway 4.

Displacement is a vector quantity. It is a measurement of the change in distance *and* the direction or the change in position of an object from a reference point. To determine the displacement of the person relative to the bus stop in Figure B1.12, you need to know both the beginning and final positions of the person, and the direction that she moved in. You can record the displacement in this case as $\Delta\vec{d}$ = 10 m [right]. This indicates that the object (the person) ends up 10 m from the reference point (the bus stop). It also indicates that the direction of travel was to the right of the reference point.

Figure B1.12 is a simple example of distance and displacement. In that example, the magnitudes of both the distance and the displacement are the same. The difference between the two is that displacement has a direction indicated. Figure B1.13 illustrates an important difference between distance and displacement. The distance (Δd) is the total distance travelled by the person on both sides of the bus stop. So Δd is 8 m. The displacement ($\Delta\vec{d}$) is the person's change in position relative to the bus stop. So $\Delta\vec{d}$ is only 2 m [left].

Note that you are describing motion when you record distance travelled and displacement. You must indicate this by using the "Δ" notation to indicate a change in the distance or the position of the object.

FIGURE B1.13 The difference between distance and displacement:

- The distance travelled by the person is Δd = 3 m + 5 m = 8 m.
- The displacement of the person relative to the bus stop is $\Delta\vec{d}$ = 3 m [right] + –5 m [left] = –2 m [left].

Minds On... Classroom Scavenger Hunt

When you want to go somewhere, you need to know not only how far it is, but what direction it's in. For this activity, your teacher has hidden "treats" in four different locations in the classroom. You must use a written set of instructions to find the hidden treasure. Your group will need a set of instructions, a metre-stick, and a large blackboard protractor. Begin at the given starting point, and follow the instructions until you locate the treasure.

On a sheet of graph paper, use a student ruler and a student protractor to sketch a map showing how you found the treats. This map is a scale drawing showing the vector arrows of your hunt.

How to Identify Vector Directions

In the example shown in Figure B1.13, the vector directions given were [right] and [left]. These vector directions were determined using the *x*-axis method. You may also have seen vectors that refer to the compass directions: north, south, east, and west. For example, a plane flying from Calgary to Regina would have an "[E]" vector, which stands for "east." This vector direction is determined using the navigator method.

The X-Axis Method

The *x*-axis method for determining vector directions uses the mathematical method of setting up a coordinate system grid with an "*x*" axis and a "*y*" axis, similar to a graph. Figure B1.14 shows the grid for the *x*-axis method. Directions are stated from the *x*-axis, which is the starting reference point at 0°. From there, directions are determined in a counterclockwise direction.

Directions given along the *x*- and *y*-axis lines are given positive or negative values.

- [Up] and [right] are positive.
- [Down] and [left] are negative.
- Directions between the axis lines are given only in degrees and are not given a positive or negative value.

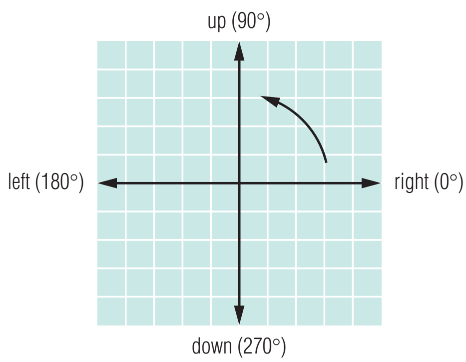

FIGURE B1.14 The *x*-axis grid for determining the directions of vectors

Example Problem B1.4

Use the *x*-axis method to determine the directions of the vectors A, B, C, and D shown in Figure B1.15. Give the magnitude and direction for each vector.

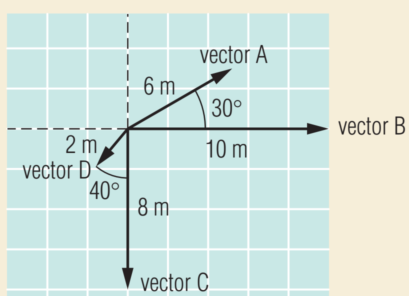

FIGURE B1.15 Vectors A, B, C, and D for Example Problem B1.4

The magnitude and directions of the vectors in Figure B1.15 are:
vector A = 6 m [30°]
vector B = 10 m [right]
vector C = –8 m [down]
vector D = 2 m [230°]

Practice Problem

6. A ball is rolling at a velocity of 2 m/s [135°]. Use the *x*-axis method to sketch this vector on a grid.